
Energy Transformations in a Land-Grant College: The Great Lakes Bioenergy Research Center

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The scientists of the DOE Great Lakes Bioenergy Research Center are eager to help solve what is arguably the largest socially, environmentally, politically, and economically significant challenge of our time—the need for new, renewable sources of energy.—Tim Donohue¹

In August of 2006, the College of Agriculture and Life Sciences (CALS) at the University of Wisconsin-Madison welcomed a new dean, Molly M. Jahn, from Cornell University. Dean Jahn joined CALS shortly after publication by the US Department of Energy (DOE) of a document titled “Breaking the Biological Barriers to Cellulosic Ethanol” and DOE’s subsequent call for bioenergy research centers (DOE, 2006; Fig. 1). Several CALS faculty and colleagues at Michigan State University had participated in discussions and development of the DOE document and were carefully following the steps this agency was taking to develop bioenergy research centers in the United States. Earlier that summer, I had a visit from two of those faculty members who were anxious to begin discussions about a proposal to develop a strong and strategic thrust in bioenergy in our college. Among the faculty with an interest in this area was Tim Donohue, a microbiologist whose work included photosynthetic bacteria and energy production from microbes. These scientists were anxious to develop a large-scale effort within CALS and on the UW-Madison campus as a whole on bioenergy, and the DOE request for proposals fit perfectly in the framework of their thinking.

Within a week of her arrival, Dean Jahn convened this group of scientists to discuss opportunities at the federal level in bioenergy. These meetings led to the eventual submission of a proposal to DOE. The group formed partnerships with colleagues at several universities, including Michigan State University, Illinois State, Iowa State, University of Florida, and with two national labs as well as businesses. To form the core academic

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partnership, the group decided that the best arrangement would be to locate the primary centers of effort at Wisconsin and Michigan. Working closely with scientists and administrators at Michigan State University, including Steve Pueppke, Mike Thomashow, and Ken Keegstra, the group put forward a proposal for a Great Lakes Bioenergy Research Center (GLBRC), the purpose of which is to remove bottlenecks in the bioenergy pipeline.

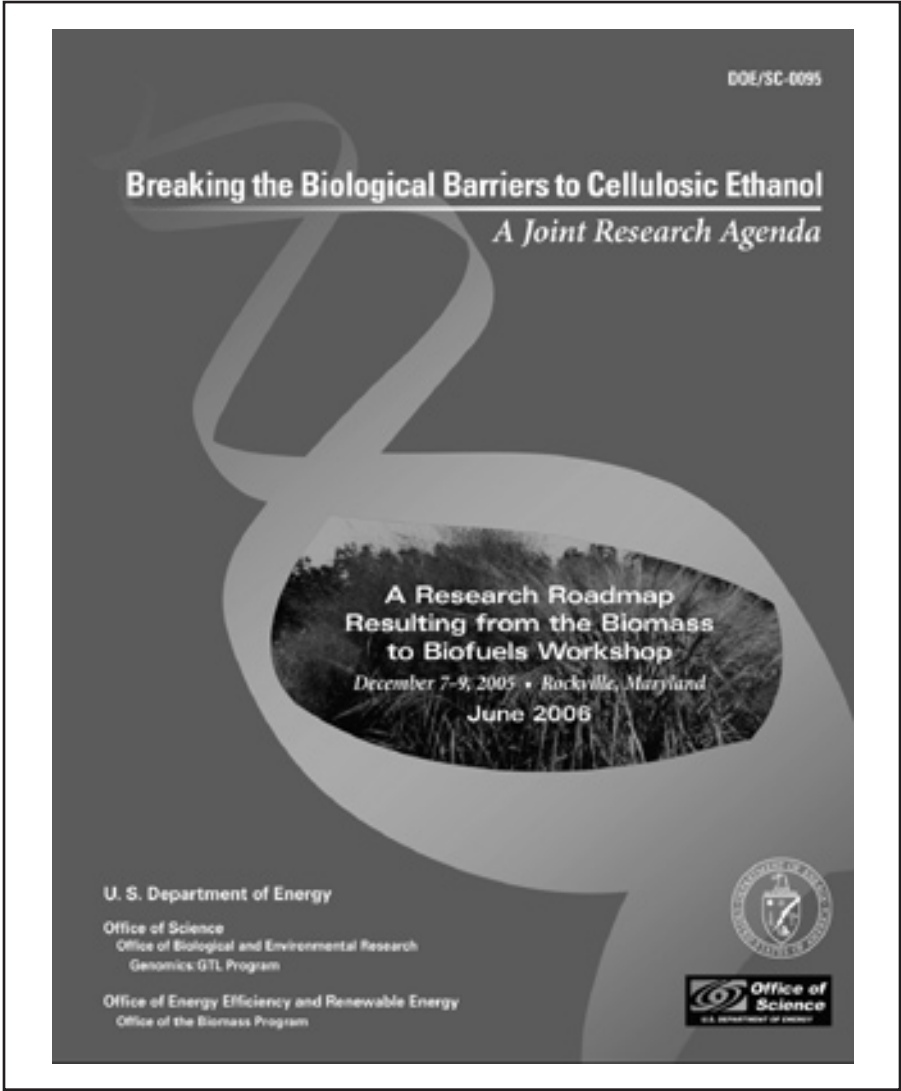


Figure 1. “Breaking the Biological Barriers to Cellulosic Ethanol,” published in June, 2006, was a primary document used by the GLBRC to map out its proposal to the Department of Energy.

Dean Jahn led an effort to secure state support for the proposal through extensive conversations and partnership-building with the University of Wisconsin System, the Office of the Governor, the Office of Energy Independence, and other state agencies. Similar efforts were led by Dr. Pueppke in Michigan. Ultimately, substantial matching support was offered by the States of Michigan and Wisconsin towards the GLBRC proposal in the form of additional faculty positions to work on bioenergy, new facilities in which to conduct research, and funding to support research collaborations. The proposal included a unique emphasis on sustainable practices throughout all aspects of the bioenergy pipeline, as well as an education and outreach thrust to take information from the Center out to students and citizens, as well as to the broader scientific community. Notification of funding was received in the summer of 2007, and work began in the fall of 2007 on the campuses of the University of Wisconsin-Madison and Michigan State University. The work of the Center is conducted under the leadership of Professor Donohue and a management team, and is carried out by a cadre of several dozen scientists on each of the two main-partner campuses.

LOCATION AND OBJECTIVES

The GLBRC is located in one of the world's most productive agricultural regions, and, as such, is able to draw strength from expertise in public- and private-sector interests in agriculture. Center scientists are exploring diverse approaches to converting sunlight via various plant feedstocks—agricultural residues, wood chips, and grasses—into biofuels. In addition to its broad range of scientific research projects, the GLBRC is collaborating with agricultural researchers and producers to help develop the most economically viable and environmentally sustainable practices for bioenergy production. Formal partners in the GLBRC include the University of Florida, Iowa State University, Illinois State University, Lucigen Corporation, Oak Ridge National Laboratory, and the Pacific Northwest National Laboratory.

The GLBRC brings together expertise in grain-crop production, forestry and paper production, engine manufacturing, agricultural equipment manufacturing, abundant natural resources, and world-class university campuses (Fig. 2). Together with industry partners, this coalition of scientists and their institutions makes up a formidable team to advance the cause of bioenergy in the United States.

RESEARCH THRUSTS

To increase the contribution of biofuels to the US energy portfolio, the GLBRC will conduct fundamental, genomics-based research to remove bottlenecks in the biofuel pipeline. There will be five major research thrusts, each of which has a leader on one campus and a complementary partner on the other campus.

Improved Plant Biomass

Among the bottlenecks in using biomass for bioenergy production are the inability to degrade the major constituents of cell walls (cellulose, hemicellulose and lignin) and the inability of many plant species to store carbon in energy-rich hydrocarbons. The GLBRC

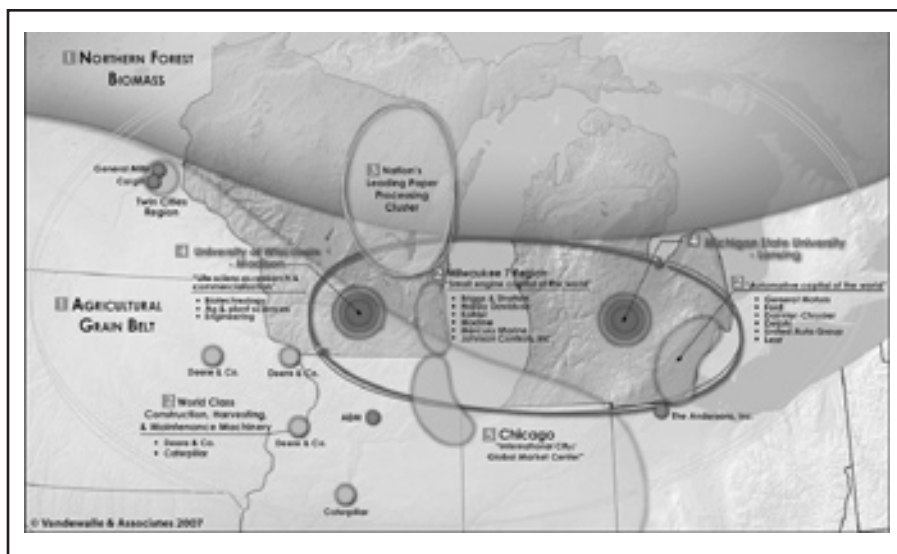


Figure 2. The Great Lakes Basin is one of the world's foremost economies, rich in academic expertise, engine and equipment manufacturing, natural resources, and highly productive agricultural land.

will strive to increase the yields of easily degraded polysaccharides within cell walls and to increase the yields of hydrocarbons in biomass tissues.

Improved Biomass Processing

Processing plant biomass into sugars is another biofuel-production bottleneck. The long-term goal of the GLBRC will be to develop new physical and biological strategies for processing plant-biomass feedstocks (corn stover, switchgrass, poplar, *etc.*) envisioned for the bioenergy pipeline.

Conversion of Biomass into Energy Products

To increase the contribution of biofuels to the US energy portfolio, plant-derived chemicals must be efficiently converted to bioenergy compounds. The long-term goals of the GLBRC are to improve methods for conversion of cellulosic biomass into ethanol and to develop novel ways to convert plant material into hydrogen, electricity and other chemical feedstocks that can replace fossil fuels.

Development of a Sustainable Bioenergy Economy

For a bioenergy economy to positively impact the US energy sector, it must be integrated into agricultural, industrial and behavioral systems. The GLBRC will develop economically and environmentally sustainable best practices for the entire biofuels-production cycle.

Enabling Technologies for Bioenergy Research

To realize these goals, the GLBRC will deploy high-throughput technologies, integrate

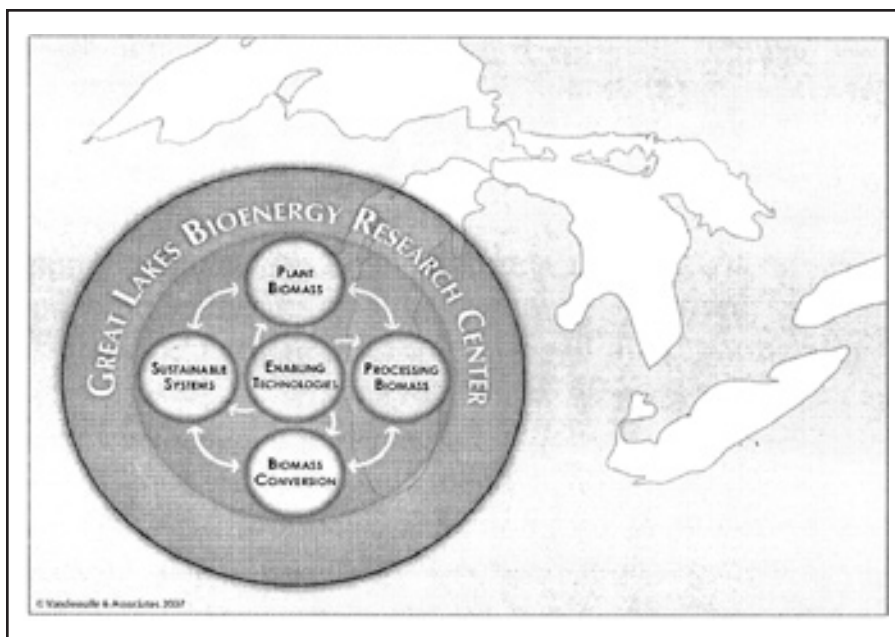


Figure 3. The five thrusts of the Great Lakes Bioenergy Research Center.

information from computational, physical, and biological approaches, and develop predictive models for relevant enzymes, pathways and networks. Thus, the center's success hinges on the application of enabling biological and physical systems and computational approaches to biomass production, processing, conversion, and sustainability.

INDUSTRY PARTNERSHIPS

The GLBRC will generate linkages with the private sector that will help bring technologies to the marketplace. New technologies developed at the GLBRC will be tested in production-line facilities.

EDUCATION AND OUTREACH

With a history of excellence in the land-grant missions of education, training, and outreach, GLBRC academic partners are deeply committed to training the bioenergy leaders of tomorrow while removing today's bottlenecks in the biofuels pipeline. The partners will offer new bioenergy-focused summer research programs, laboratory training, seminars, and special courses. Working within existing programs at partner universities, GLBRC scientists will develop workshops and educational modules for K–12 teachers on carbon chemistry, sustainability, and biodiversity issues related to biofuel production. Additionally, Center researchers will develop informative materials and host public forums to raise awareness of, and generate support for, biofuels among farmers and communities.

EXPLANATION OF PARTNERSHIPS

The establishment of the GLBRC on our university campuses represents a new model for large-scale research and development with a federal partner. Achieving the objective of removing bottlenecks from the bioenergy pipeline is a monumental national goal. The urgency of this new national goal and the scope of the funding and oversight by the DOE require a new approach to engagement on the university side. The GLBRC has assembled a team of scientists across the United States with relevant expertise.

To create a better understanding of the larger context that ultimately influences the direction and acceptance of new biotechnologies, the GLBRC's lead partner, the University of Wisconsin-Madison, will draw on world-renowned expertise in genomics-enabled analyses of plant and microbial pathways, networks, and systems; computational analysis of bioenergy proteins, organisms, and ecosystems; and discovery, production, and improvement of bioenergy enzymes. However, the work of the Center will not be accomplished without extensive partnerships with both the public and private sectors. Accordingly, the University of Wisconsin-Madison entered into subcontracts with a number of partners with complementary strengths.

The primary partner and subcontractor is Michigan State University (MSU), East Lansing; MSU researchers are experts in the breakdown and synthesis of plant cell walls, oils, and other polymers; the breakdown of cellulose in plant stems, stalks, and leaves, including trees and other woody plants; and the development of biofuel-production practices that are both environmentally and economically sustainable. The University of Florida, Gainesville, as a GLBRC partner institution brings expertise in the conversion of lignocellulosic biomass into ethanol using novel bacterial agents. Iowa State University (ISU), Ames, brings expertise in constructing economic models of biomass practices. Scientists at Illinois State University, Normal, work on genetic and molecular analyses of switchgrass. Lucigen Corporation, Middleton, Wisconsin, provides valuable expertise in bioprospecting for new biomass-deconstruction enzymes. DOE's Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee, will enable the GLBRC to evaluate biomass sustainability by modeling ecosystem changes that could result from the biofuel-production cycle. DOE's Pacific Northwest National Laboratory (PNNL), Richland, Washington, will enable the GLBRC to complete high-throughput analyses of bioenergy proteins and organisms and analyze the entire life cycles of bioenergy practices.

A major push will be the search for cellulose-degrading enzymes. To discover and improve enzymes for biomass deconstruction, GLBRC researchers are conducting high-throughput screens of genetic material from specialized ecosystems such as bacteria that live in association with tropical leaf-cutting ants. University scientists plan to examine the environmental and socioeconomic dimensions of converting biomass to biofuel. To determine the best practices for biofuels production, GLBRC researchers will study issues such as minimizing energy and chemical inputs for bioenergy-crop production; reducing greenhouse-gas emissions from the entire biofuel-production life cycle; and understanding the environmental impacts of removing leftover stalks, stems, and leaves of food crops. They will also study the social and financial incentives needed to promote adoption of more environmentally beneficial practices.

FLEXIBLE MANAGEMENT

Establishing the GLBRC on university campuses requires a flexible approach to research administration. Unlike individual-investigator grants and contracts, the GLBRC bears more similarity to a large commercial enterprise run from university facilities in that its sponsor, the Department of Energy, has a much greater hand in the development, progress, and workflow for the Center than a typical sponsor would have for an individual grant. A cooperative agreement between the university and DOE sets out terms and conditions that are more stringent than a standard grant, but perhaps less stringent than a standard contract. This middle ground provides enough flexibility for discovery, but also enough accountability to justify the level of investment. For example, per DOE requirements, revenue streams that will be created from licensing technology produced in the Center will be returned to the campuses in a conventional manner; however, the revenue will be returned to the Center at greater percentages than standard royalties produced from standard intellectual property on our campuses. Thus, the Center has a greater chance of being self-sustaining through additional royalty flow as a result of discoveries by its scientists.

Likewise, the development of a management team to run the Center is of utmost importance to the DOE. As such, great emphasis has been placed on the development of an over-arching managerial and administrative structure. Participation in the management of a center of this magnitude puts added strain on the time that faculty members have to participate in their programmed duties of research, instruction, and outreach. In this case, it is incumbent upon the institution to work with faculty and their departments to find solutions to problems previously not encountered. An example would be teaching or mentoring activities that require large time commitments in particular semesters, in conflict with management-team duties. The faculty member must be able to participate in faculty activities, but fulfill the management team's requirements as well. In such cases, it is important that departmental, college and campus administration seek solutions to assist faculty achieve these goals. In some cases, this assistance may come in the form of financial support to hire teaching or research assistants, but in other cases it may require modification of faculty appointments to reflect additional administrative duties imposed by the Center's management. In either case, flexibility on both sides is important in order to harness the intellectual contributions of outstanding faculty while maintaining the high standards for traditional research, instruction, and outreach that have made our campuses internationally recognized.

In a similar vein, progress reporting, material transfer, conflict-of-interest management, and other administrative actions become more-substantial challenges when sponsor requirements are stricter or more detailed than standard campus practice. Such is the case for the reporting of outside activities and conflict-of-interest management, which are more stringent under DOE management than usually practiced on the campus of the University of Wisconsin-Madison, despite the fact that the latter has a well developed, robust process for managing potential conflicts for research staff. This additional layer of scrutiny requires more vigilance on the part of the Center's management team and administrators in departments, colleges, and the campus.

The overall research strategy employed by the GLBRC is described below, organized according to the five thrusts previously described.

Improving Plant Biomass

In addition to investigating how genes affect cell-wall digestibility in model plants—cornstalks, and switchgrass—GLBRC researchers will breed plants that produce more hemicelluloses, starches, oils, or new forms of lignin that are easier to process into fuels. Plant oils have twice the energy content of carbohydrates and require little energy to extract and convert then into biodiesel. In the United States, biodiesel is produced primarily from soybean; however, oil yields per acre of soybean need to be improved. GLBRC researchers aim to increase the energy density of grasses and other nontraditional oil crops by understanding and manipulating the metabolic and genetic circuits that control synthesis and accumulation of oils and other easily digestible, energy-rich compounds in plant tissues.

Improving Biomass Processing

Located at the intersection of America's agricultural heartland and its abundant northern forest biomass, the GLBRC has access to a rich diversity of raw biomass for study. GLBRC biomass-processing research will discover and improve natural cellulose-degrading enzymes extracted from diverse environments. Improved enzymes created by the GLBRC protein-production pipeline will be used in analyzing a range of plant materials and pretreatments. Scientists will strive to find conditions to identify the best combination of enzymes, chemicals, and physical processing for enhancing the digestibility of specific biomass sources. Researchers will identify and quantify small molecules generated in various pretreatment methods and examine how they impact biofuel yield. Decreasing the costs of producing and using enzymes to break down cellulose in plants will involve collaboration with plant-biomass researchers. They are expressing biomass-degrading enzymes in the stems and leaves of corn and other plants—essentially designing plants to “self-destruct” on cue in the biofuel-production facility.

Improving Biomass Conversion

Biomass-conversion research is driven by the need to increase the quantity, diversity, and efficiency of energy products derived from plant biomass. Cellulosic ethanol is a major focus for GLBRC research, along with improvements in biological and chemical methods for converting plant material into hydrogen, electricity, or other bioproducts that can replace fossil fuels. In addition to converting plants into energy, researchers are developing microbes that directly convert sunlight into hydrogen or electricity. To create a microbe capable of carrying out all biologically mediated biofuel-production steps, scientists are taking a somewhat novel approach. Instead of modifying an effective biomass-degrading microbe to produce ethanol, they are engineering efficient ethanol-producing microbes to produce enzymes and pathways to break down cellulose.

Fostering Sustainable Bioenergy Practices

The GLBRC will take a holistic approach to evaluating the economic and environmental sustainability of transforming biomass to biofuel. Leading this area of endeavor is G. Philip Robertson, professor of crop and soil sciences at Michigan State University. As an ecologist, Robertson focuses much of his research on the role that agriculture plays in greenhouse-gas dynamics, for which he has an international reputation. He has been the director of long-term ecological research (LTER) at the Kellogg Biological Station in Hickory Corners, Michigan, the only site in the national LTER network to focus on agriculture, for almost 20 years.

The overarching charge of the GLBRC's sustainability thrust is to improve sustainability of bioenergy practices. Researchers in this area will support the biomass-to-bioenergy pipeline by developing ecological, agricultural and life cycle practices that are economically viable and environmentally responsive.

Modeling systems will be used to predict the impacts that the biofuel-production pipeline will have both locally and globally (Figs. 4 and 5). The goal is to develop a comprehensive framework that enables the analysis of biomass cropping in reference to land-use requirements and competition, environmental consequences (*e.g.*, water balance, nitrogen balance, carbon balance, and soil quality), and competing energy technologies.

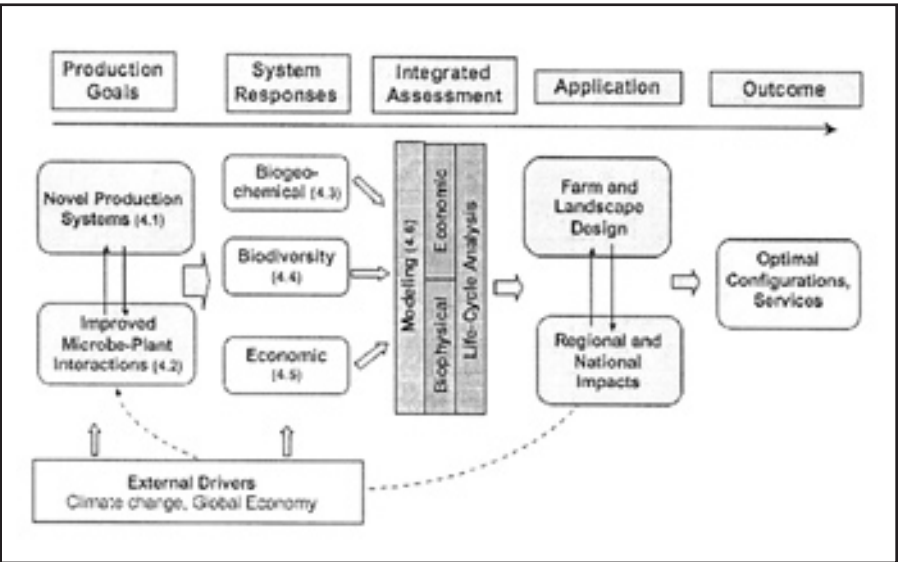


Figure 4. Determine elements of biofuel-production systems that can be optimized to improve environmental and economic sustainability. (Courtesy of GLBRC.)

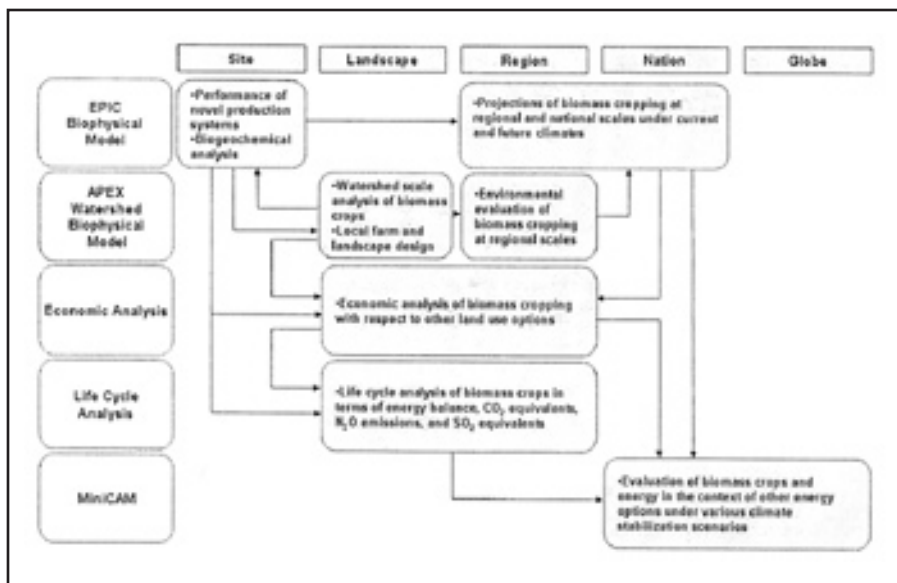


Figure 5. Determine elements of biofuel-production systems that can be optimized to improve environmental and economic sustainability. (Courtesy of GLBRC.)

Creating Technologies to Enable More-Advanced Bioenergy Research

This focus crosses all areas of research by providing cutting-edge, genomics-based technologies that enable the innovative discoveries and creative solutions needed to advance bioenergy research. GLBRC researchers will deploy high-throughput, automated screens for genes and proteins in plants and microbes that affect biomass and biofuel production; integrate information from multiple research approaches; and develop predictive models for relevant enzymes, pathways, and/or networks that can guide the development of new plants, enzymes, and/or microbes that would be useful in a biofuel-production pipeline.

SUMMARY

The establishment of the GLBRC on university campuses represents a new model for large-scale research and development with a federal partner. Achieving the objective of removing bottlenecks from the bioenergy pipeline is a monumental national goal. The GLBRC has outlined five major thrusts that lay out a plan for improving plant biomass and its conversion to energy products for the United States. One of the unique elements of the center is its sustainability thrust, emphasizing practices throughout the bioenergy-production pipeline that focus on environmental and resource issues and sustainable practices. The thrusts are also complemented by an education and outreach effort to take information from the Center to students and citizens throughout the country.

Universities have been designed to respond well to national goals. However, this has primarily been achieved by individual investigators or groups of investigators working together in small to mid-size teams, often with great success. Through such programs, outstanding partnerships have been built between public-sector and federal-agency scientists. However, the urgency of this national goal on bioenergy and the scope of the funding and oversight by the Department of Energy require a new approach to engagement on the university side. For the GLBRC to be successful, we will need to advance our partnerships in new ways with the states where our campuses are supported. We will need to enhance our ability to be flexible with respect to faculty appointments and responsibilities in order to meet project goals. Ultimately, the paths that clear as this Center develops will blaze new trails for federal-state partnerships in science and technology for the twenty-first century.

REFERENCE

Department of Energy (DOE) (2006) Breaking the Biological Barriers to Cellulosic Ethanol. Washington, DC: US Department of Energy.



IRWIN GOLDMAN serves as vice dean and associate dean for research in the College of Agricultural and Life Sciences at the University of Wisconsin at Madison. His responsibilities include faculty hiring and development, budget, extramural grants, management of the college's Research Division, and research compliance. He is also a professor in the Department of Horticulture.

He has a BS in agricultural science from the University of Illinois, an MS in crop science from North Carolina State University, and a PhD in plant breeding and plant genetics from the University of Wisconsin.

Dr. Goldman served as a postdoctoral associate researching maize genetics at the University of Illinois before joining the faculty at Madison in 1992. He teaches courses in plant breeding and genetics, evolutionary biology and vegetable crops. Goldman is responsible for germplasm development and breeding and he conducts research on the genetics of cross-pollinated vegetable crops, primarily carrot, onion and beet.